CONSCAN Implementation at DSS 13

R. M. Gosline
R. F. Systems Development Section

The ability to do automatic boresighting of a large parabolic antenna without a monopulse feed or rotatable subreflector is desirable. A conical scan (CONSCAN) technique based on the movement of the main reflector under computer control has been developed. The functional features of the hardware and software as implemented at DSS 13 are described. Application to very precise antenna pointing is possible.

I. Introduction

Conical scan (CONSCAN) techniques (by scanning the main reflector) were demonstrated at DSS 13 in 1966 utilizing an SDS 910 computer, the 26-meter-diameter antenna, and a test transmitter located at the DSS 13 collimation tower. Successful boresight measurements were obtained on a static target although ground reflections and computer limitations prevented complete success. The tracking system was then interfaced with the SDS 930 computer and the program re-written in real-time Fortran II. Peripheral equipment on line included two magnetic tape units, a line printer, and a card reader/punch providing adequate development and de-bugging capability. A complete angle tracking program was developed with the conical scan technique being one of several options.

II. Algorithm

A mathematical analysis of the general technique is described in Refs. 1, 2, and 3.

The actual implementation preceded the detailed analysis on the recognition that a circular scanning antenna will cause a sinusoidal variation in the received signal whose amplitude and phase (with respect to the scanning function) contain information with which to improve the boresight.

The algorithm may be simply developed by fitting a sinusoid of the form

$$y = D + R\cos(\omega t - \phi) \tag{1}$$

to the sampled receiver power y_i by the method of least squares as detailed in Ref. 4. Expansion of Eq. (1) and substituting

$$A = R\cos\phi$$
$$B = R\sin\phi$$

yields

$$y = D + A\cos\omega t + B\sin\omega t$$

where A and B are the axial components of the boresight error. The least squares sum S is

$$S = \sum_{i=0}^{n-1} [y_i - (D + A\cos\omega t_i + B\sin\omega t_i)]^2$$

The scan frequency ω is known. S may be minimized by setting

$$\frac{\partial S}{\partial A} = \frac{\partial S}{\partial B} = \frac{\partial S}{\partial D} = 0$$

This yields

$$D = \frac{1}{n}\sum y_i \text{ (the dc component)}$$

$$A = \frac{2}{n}\sum y_i \cos\omega t_i$$

$$B = \frac{2}{n}\sum y_i \sin\omega t_i$$

The boresight error magnitude and direction may now be found from

$$R = \sqrt{A^2 + B^2}$$

and

$$\phi = \arctan B/A$$

but the A and B summations are applied directly as the azimuth and elevation corrections. Figure 1 is a functional diagram of the implementation. The circular scan is generated by adding sine and cosine functions to the azimuth and elevation ephemerides. The signal power samples (averaged over a one-second period) are multiplied by the appropriate sinusoidal function and summed over a complete scan cycle in each axis. A gain factor is applied to control stability before the corrections are added to the nominal ephemerides. The corrections are accumulative, i.e., the total corrections C, as a result of m complete cycles, is

$$C = G\sum_{i=1}^{m} A_i$$

In a stable condition the A_i terms become small.

III. Program Description

The program is best summarized with a brief description of the 15 control options that enable various combinations of modes. These options are selected by the SDS 930 typewriter.

(1) *Position offsets.* Provides for entering fixed-position offsets in azimuth, elevation, hour angle, or declination.

(2) *Sidereal rate mode.* Generates a sidereal rate from either right ascension or sidereal hour angle and declination coordinates.

(3) *Scan mode.* Enables conical scan mode and allows for input of scan radius, period, and a gain factor.

(4) *Stop mode.* Stops conical scan mode, on–off mode, and simulation mode, and removes all position and rate offsets.

(5) *3-Day fit mode.* Generates a second-order fit to three days of coordinates for tracking planets from almanac data.

(6) *Polynomial mode.* Generates an ephemeris from standard polynomial cards as supplied by the "PLACE" predicts program.

(7) *Zero az–el mode.* Generates an azimuth and elevation ephemeris of zero plus offsets.

(8) *Zero HA–dec mode.* Generates a local hour angle and declination ephemeris of zero plus offsets.

(9) *Time offset.* Allows for time offsets to any of the ephemeris modes.

(10) *Read offset table.* Reads punched paper tape containing offset data to be used as pointing corrections.

(11) *On–off source mode.* Provides the following antenna sequence for radio source calibration work:

   (a) Conical scan

   (b) Off source (in azimuth if elevation < 60 deg)

   (c) On source

   (d) Off source

   (e) Repeats (c) and (d) three times

   (f) Return to (a)

(12) *Track tolerance.* Provides for changing the nominal tracking tolerance of 0.010 deg. In the conical scan and on–off modes, the servo tracking error is checked against the tracking tolerance before the next angle increment is allowed to proceed.

(13) *Simulation mode.* Simulation of the receiver output and servo/readout system allows internal checking of the SDS 930 hardware and software.

(14) *Zero offset table.* Removes all table offsets from read offset table mode.

(15) *Rate offsets.* Provides for rate offsets in azimuth, elevation, hour angle, and declination.

Use is made of the priority interrupt system so that modes and parameters can be changed while the antenna is under computer control and tracking a target.

IV. Results

Typical offset data obtained by conical scanning are shown in Fig. 2. Even the fine structure of these plots is repeatable. An apparent periodicity of 13⅓ deg corresponds to one pole of the 27-pole resolver in the Datex readout system, and indicates a possible malfunction of that system.

Figure 3 is a typical plot obtained after using the offset data previously obtained and repeating the conical scan procedure. Very precise tracking is obtainable by this technique as demonstrated by Fig. 3.

The minimum useful scan period is about 60 seconds, depending on wind conditions and servo performance, which represents an order of magnitude improvement in measurement time over previous manual methods. Further data are needed to compare with the theoretical analysis in Refs. 1, 2, and 3.

With the completion of the development phase, it is now possible to implement the technique back into an SDS 910 or 920 computer for boresight measurements in the Deep Space Stations.

References

1. Ohlson, J. E., *Performance Analysis of Conical-Scan Tracking: Part I. Tracking of Radio Sources,* Document 3333-71-208, Oct. 20, 1971 (JPL internal document).

2. Ohlson, J. E., *Performance Analysis of Conical-Scan Tracking: Part II. Tracking of Spacecraft,* Document 3333-71-239, Dec. 2, 1971 (JPL internal document).

3. Ohlson, J. E., *Performance Analysis of Conical-Scan Tracking: Part III. Gain Fluctuation Effects,* Document 3333-72-076, Mar. 23, 1972 (JPL internal document).

4. Gosline, R. M., *Conical Scan Simulation,* M.S. thesis, West Coast University, Los Angeles, Calif., May 1, 1970.

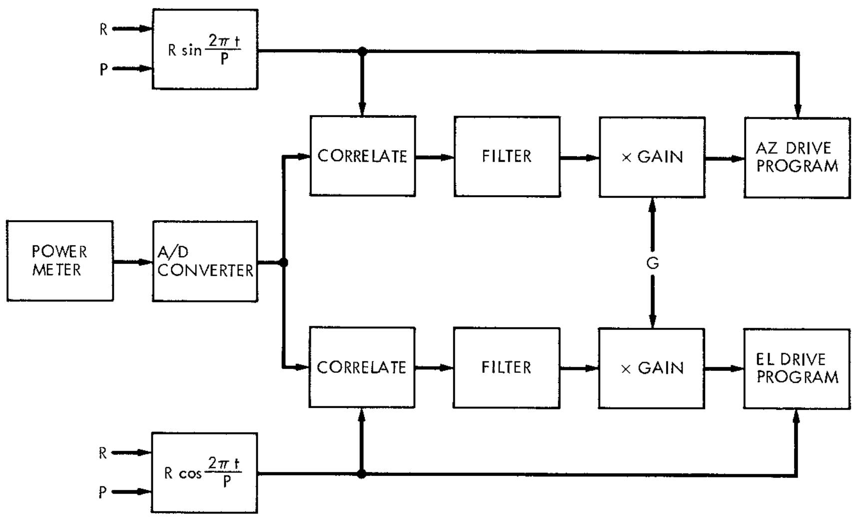

Fig. 1. Conical scan functional diagram

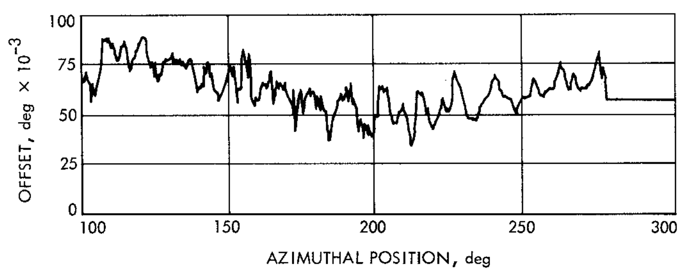

Fig. 2. Boresight errors before table corrections applied

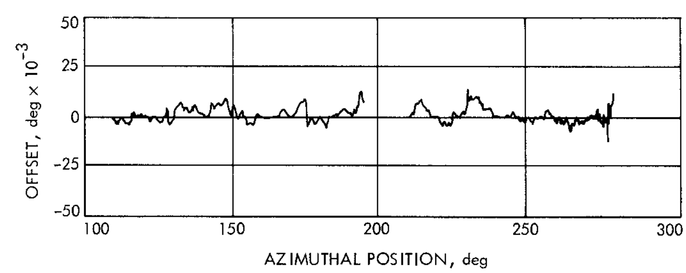

Fig. 3. Boresight errors after table corrections applied